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The Role of Familiarity in Rhythmic Timing and Beat Perception

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Abstract

Behavioural and neural differences associated with strong and weak-beat rhythms may indicate that strong-beat rhythms are more familiar stimuli than weak-beat rhythms, or differences may be because intervals in strong-beat rhythms are more easily encoded relative to a beat. To test these different possibilities, participants were trained to reproduce strong-, weak-, and non-beat rhythms over 4 days, in an attempt to equate familiarity across the different categories of rhythms. On a fifth day, participants were tested on their ability to reproduce these same rhythms at learned, slower, and faster rates, as well as novel rhythms. Participants improved performance on all rhythms across the 4 training sessions, but were still more accurate for strong-beat than weak- or non-beat rhythms after training. Accuracy for rescaled (slower and faster) versions of the rhythms was not different from accuracy for learned rates, and all trained rhythms, regardless of rate, were reproduced more accurately than novel rhythms. Though the results are not conclusive about the two proposed explanations for behavioural and neural differences between strong and weak-beat rhythms, findings indicate that possibly both familiarity and beat strength play roles in improving timing performance.

Keywords

Rhythm, Beat, Perception, Encoding, Rescaling, Timing, Familiarity, Predictability, Music.

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Chapter 1

1 Introduction

The ability to time movements with external cues is essential for interacting with the environment. Movement timing dictates performance in simple tasks, such as catching a ball, and in complex movements, like dancing to music. The accuracy of timed movements is influenced by relevant stimulus features, such as its regularity or predictability. One unique feature of music that improves timing performance is the feeling of a steady pulse or "beat" that unfolds over time. The influence of the beat on movement timing is evident in humans, who tend to spontaneously synchronize with the beat, such as with clapping or foot tapping.

1.1 Beat Perception

Though melody, harmony, and lyrics can all contribute to perceiving the beat in music, timing information alone can induce beat perception (Grahn & Brett, 2007). This can be demonstrated by beat perception occurring in rhythm even when all musical parameters of the tones are identical, apart from the duration that separates their onsets (inter-onset interval) (Grahn & Brett, 2007). Varying interval duration is thought to influence beat perception through a process called perceptual accenting (Povel & Okkerman, 1981). Perceptual accents are perceived increases in stimulus salience in the absence of any true differences between the stimuli. For example, the second sound in a pair of sounds is generally perceived as more salient (e.g., louder) than the first, even when no acoustic differences are present (Povel & Okkerman, 1981). When the inter-onset intervals in a rhythmic sequence are arranged such that perceptual accents occur at evenly spaced

points in time (e.g. every 500ms), a strong beat percept is induced (Bouwer et al., 2018). The beat percept can be weakened by rearranging the same inter-onset intervals that make up a strong-beat rhythm so that the perceptual accents are no longer evenly spaced (Figure 1). In addition to perceptual accents, inducing beat perception may require sequences of integer-ratio intervals, in which the durations of the intervals are related by a common base unit duration (e.g., 2:1, 2:3) (Grahn & Brett, 2007). Integer-ratio intervals are typical in music, where rhythm conforms to a hierarchical metric structure so that the timing between notes is related as a fraction of a whole measure (e.g., 1/4 notes or 1/8 notes). Thus, rhythms with intervals that are not integer-ratio related (e.g., 1.4:1 or 3.6:1), which therefore cannot be notated in music, generally do not induce beat perception (Grahn & Brett, 2007). In sum, manipulating the temporal characteristics of rhythmic sequences, whether by spacing perceptual accents or altering interval relationships, allows for rhythms to be created that have a strong beat, a weak beat, or no beat. In beat perception research, strong-beat rhythms are directly compared to weak- and non-beat rhythms to study effects of beat strength without any other acoustic differences confounding the comparison.

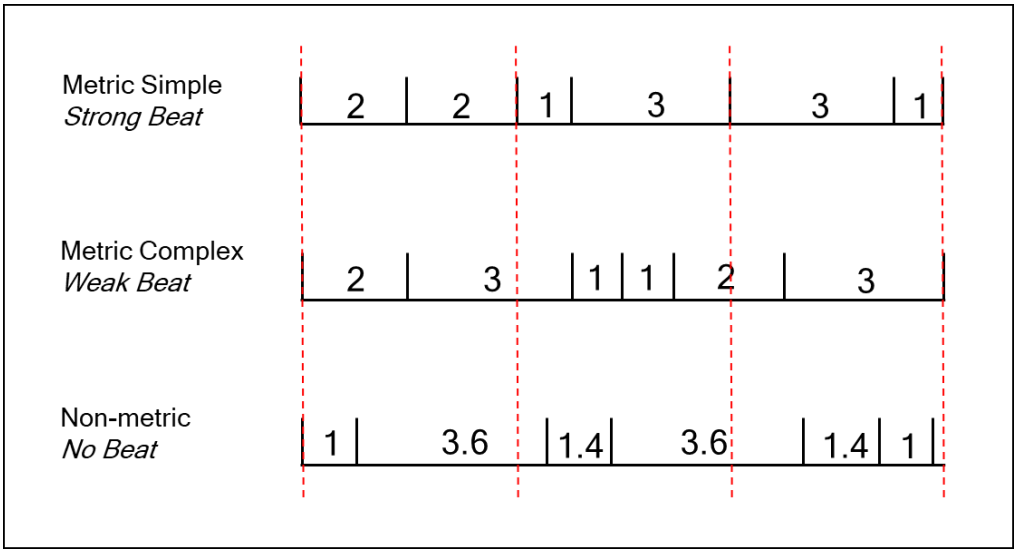

Figure 1. Example of Rhythmic Conditions (adapted from Grahn & Brett, 2007). Black vertical lines represent acoustic tones, red dashed lines indicate beat locations according to perceptual accents. Numbers indicate interval durations as ratio relationships.

1.2 Behavioral and Neural Correlates of Beat Perception

There are specific neural correlates associated with rhythm and beat perception. Studies using functional magnetic resonance imaging (fMRI) report activity in the ventrolateral prefrontal cortex, cerebellum, supplementary motor area and basal ganglia while listening to rhythmic sequences (Chen, Penhune, & Zatorre, 2008). In a study investigating neural correlates of beat perception specifically, subjects were asked to discriminate between rhythms that had either strong, weak, or no beat presence (Grahn & Brett, 2007). Rhythms with a strong beat were associated with greater activity in the basal ganglia and supplementary motor area (SMA), compared to weak- and non-beat rhythms. Functional connectivity analysis has also shown correlated activity between these two regions, which may suggest the role of a striatal-cortical loop during beat perception (Grahn & Rowe, 2009). Together, these findings suggest that the basal ganglia play a role in beat

perception, and the necessity of the basal ganglia's contribution to beat perception is confirmed by the deficits in patients with compromised basal ganglia functioning. Specifically, Parkinson's disease patients do not show the same performance improvement on a rhythm discrimination task for strong-beat rhythms as do healthy controls (Grahn & Brett, 2009). Therefore, without proper basal ganglia functioning, the advantages of beat presence are reduced, suggesting that the basal ganglia play a necessary functional role in beat perception. So far, beat perception research has not been conclusive about the specific functions of the basal ganglia and SMA in beat perception.

1.3 Role of the Basal Ganglia and SMA in Beat Perception

Though the areas associated with beat perception are more traditionally viewed as motor areas, they are also implicated in timing and time perception functions. The supplementary motor area is often reported for various timing and time perception tasks (Schwartze, Rothermich, & Kotz, 2012). Some suggest that the SMA responds to sequential stimuli, such as motor sequences and number sequences (Cona & Semenza, 2017), and as rhythms are essentially sequences of time intervals, the SMA's role may be in processing the sequential aspect of the stimuli. However, the SMA is also cited for time discrimination tasks and the perception of subsecond (durations under 1000 ms) intervals, even outside of a sequential context (Schwartze, et al., 2012), suggesting a particular role in interval processing.

Though structures in the basal ganglia have been implicated in perceptual and timing functions (Kotz, Schwartze, & Shmidt-Kassow, 2009), the specific function of the basal ganglia in beat perception is less clear. One explanation is that the basal ganglia are responsible for internally generating predictions of future beat times, based on the

detection of the regular beat structure. This is supported by evidence showing that relative timing tasks, which require internalizing a unit of time, are correlated with basal ganglia and cortical activity, whereas absolute timing, in which internalizing a common temporal unit is not useful, is related to activity in other brain areas (Teki et al., 2011). Furthermore, in a study comparing neural activity during finding a new beat versus continuing an already perceived beat, the basal ganglia were most active when continuing the beat, in which internal generation of the beat is greatest (Grahn & Rowe, 2012). In addition to generating a beat, the beat continuation task required prediction of the beat interval. Therefore, the function of the basal ganglia during beat perception may be in the prediction of upcoming interval onsets relative to the perceived beat. As mentioned previously, a strong beat can provide structure to a rhythm, thus making events that occur in time with the beat predictable (whether occurring "on" the beat, or at a time interval related to the beat) (Grahn & Rowe, 2012). Thus, the regularity of strong-beat rhythms allows prediction of interval onsets, which may account for the increased basal ganglia activity compared to weak- and non-beat rhythms.

An alternative explanation for the neural findings in beat perception suggests that familiarity-based, rather than regularity-based, predictability of strong-beat rhythms is responsible. As the daily human environment often includes music, strong-beat rhythms may be more familiar to human listeners, and therefore more predictable because of that familiarity, than non-beat rhythms. This explanation is consistent with findings implicating the basal ganglia in prediction without temporal regularity, such as reward prediction (Haruno & Kawato, 2005), and movement prediction (Schiffer & Schubotz, 2011). Basal ganglia activity has also been reported in rhythmic speech, which

encompasses a temporal predictability that does not require internal beat generation (Kotz, Schwartze, & Shmidt-Kassow, 2009).

Familiarity-based predictability may explain improved memory and timing for strong-beat rhythms. People better detect small changes in interval timing for rhythmic patterns that are common to the individual's culture, compared to patterns from other cultures, with which they would have less long-term exposure (Hannon, Soley, & Ullal, 2012). Even with short-term exposure (i.e. the length of an experimental session), repeated listening to rhythms elicits faster reaction times for correct responses to rhythm discrimination tasks (Tillmann, Stevens, & Keller, 2011). Short-term exposure also improves reproduction accuracy (Tillmann, et al., 2011). For example, during a repeated serial reaction time task, participants implicitly learned the timing of one 3-interval sequence, either the pattern 2:2:3 or 2:2:4. After exposure, synchronization and reproduction accuracy for the 2:2:3 sequence was measured. Both groups had less tapping variability than a no-exposure group, and the 2:2:3-exposed group had less variability only for the 3 interval, compared to the 2:2:4-exposed group (Tillmann et al., 2011). Thus, stimulus familiarity may benefit motor timing performance, even in a short-term implicit learning design. These findings suggest that previous beat perception research may be confounded by using stimuli that differ in how familiar they are.

1.4 Current Experiment

To date, no studies have directly examined the role of familiarity-based predictability in rhythm perception for strong-beat and non-beat rhythms. To address this gap in literature, the current study examined the role of familiarity-based and regularity-based predictability in rhythm perception. The experiment was designed to equate the

familiarity of rhythms regardless of beat strength. We then probed whether weak- or non-beat rhythms were encoded similarly to strong-beat rhythms once they were equally familiar. One way that encoding representations have been probed in timing research is by measuring rescaling accuracy, or how well timing accuracy on an initially-learned sequence transfers to faster or slower rates. For example, Collier & Wright (1995) used a rescaling paradigm to highlight differences in encoding integer-related and non-integer-related intervals (Collier & Wright, 1995). Participants were trained to reproduce interval pairs that were either related by simple integer ratios (e.g. 2:1), such as the intervals occurring in strong-beat rhythms, or complex non-integer ratios (e.g. 2.72:1), which do not induce beat perception. Though participants improved performance during acquisition trials for both interval types, when asked to rescale the intervals by reproducing them in double the total duration, temporal accuracy remained only for integer-ratio intervals. Collier & Wright (1995) concluded that this distinction in rescaling ability reveals different timing mechanisms used for simple and complex intervals. In the aforementioned study by Tillmann et al. (2011), differences between exposure groups (2:2:3-exposed versus 2:2:4-exposed groups) in reproduction performance were only found when tested on faster-than-learned reproduction rates. That is, both groups performed the test stimulus at similar accuracy when presented at the learned rate, but only the group most familiarized with the test sequence transferred reproduction accuracy to a fast-rate version of the sequence. Rescaling was thus used to indicate whether participants were learning the absolute durations of intervals, or if they encoded the relationships between intervals, which would allow the performance accuracy to be transferred to the faster-than-learned test stimulus (Tillmann, et al., 2011).

Rescaling ability has not been tested in longer musical rhythms. However, musicians are known to play pieces at faster or slower rates without losing rhythmic precision, suggesting that rescaling is possible for rhythms with a beat. It is not clear, though, whether this ability is mediated by the beat, or if familiarity with the music alone allows musicians to perform such a manipulation.

In the current experiment, participants were trained to reproduce 12 unique stimuli with strong, weak, and no beat strength. In a final session, participants' reproduction accuracy was measured for the 12 trained rhythms, as well as for faster and slower versions of those same rhythms, and for 12 novel rhythms, matched for beat strength. If rhythms are encoded differentially dependent on beat presence, then rescaled weak- and non-beat rhythms should be less accurately reproduced than the trained rhythms, even though they are familiar. Alternatively, if rhythm timing accuracy depends on familiarity, then reproduction accuracy should be similar between trained and rescaled rates, regardless of beat strength, both learned and rescaled rhythms should be reproduced more accurately than the novel, unfamiliar rhythms.

Chapter 2

2 Method

2.1 Participants

28 participants (16 female) completed the experiment. Of the 28, 2 participants were removed for lack of improvement over the training period, marked by a positive slope in proportional error across the 8 blocks of rhythm reproduction. Thus, the following analysis was completed with 26 participants (15 female), ranging from 18 – 46 years of age (M = 23.39). 13 participants reported having some formal music training, ranging from 2 – 23 years (M = 5.58 years). All participants reported normal hearing.

2.2 Stimuli

Twenty-four unique rhythms were created based on the stimuli used in previous studies (Grahn & Brett, 2007). The 24 rhythms were selected to optimize uniqueness, such that small strings of intervals (e.g. 2 1 1) were balanced across stimulus sets and conditions (see Table 1), and to balance relative reproduction difficulty across beat strength conditions (based on pilot data). The rhythms were created using Matlab (Mathworks), with intervals presented as 500 Hz sine-wave tones, and the duration of each interval was measured as the onset of one tone to the onset of the next tone. The tones lasted the duration of each interval, minus 40 ms, so that each interval onset was distinguishable from the previous tone. Tone onsets and offsets were created with 8ms linear ramps.

Rhythms were created for each of three conditions: Metric simple (MS), metric complex (MC), and non-metric (NM) rhythms were created, which elicited a beat percept that was strong, weak, or non-existent, respectively. Rhythms in metric simple and metric

complex conditions contained intervals that were integer-related, such that intervals were integer multiples of the shortest duration (i.e. 2, 3, or 4 times a base unit duration of 1). The shortest duration varied from 210-290 ms (see below). The non-metric rhythms contained intervals that were non-integer-related (1:1.4:3.6:4). Metric simple rhythms were designed to elicit perceptual accents at evenly spaced timepoints (e.g. every 4 base units) throughout the rhythm (Povel & Okkerman, 1981; Grahn & Brett, 2007); these accents indicate the beat to the listener. Metric complex and non-metric rhythms had perceptual accents that did not occur at evenly spaced points in time, thus making it more difficult or impossible to perceive a beat (Povel & Okkerman, 1981; Grahn & Brett, 2007). In all conditions, rhythms contained 6 or 7 intervals, and were ~3 seconds in total duration.

During training, all rhythms were presented and reproduced at the same rate, with the base interval duration of 250 ms. All other intervals (2:3:4) were multiples of the base unit duration. In the rescaling condition, the trained rhythms were presented at rates 8% faster and slower than the trained tempo. Thus, the base unit duration changed to 230ms in the faster condition, and 270ms in the slower condition. Intervals in the learned and rescaled rhythms were timed relative to the respective base unit durations. For example, for the rhythm 211231, participants would have learned to tap 500 250 250 500 750 250 ms intervals, and tested on the rescaled 460 230 230 460 690 230 ms intervals. A portion of the participants (n = 12) were tested on rhythms rescaled by +/– 16%, in addition to the 8% manipulation. Therefore the base units for the extra rescaling conditions were 210 ms (extra fast), and 290 ms (extra slow).

Stimuli were placed into 4 counterbalanced sets of 12 unique rhythms (Table 1). Each set contained 4 rhythms of each metric condition, 2 with 6 intervals, and 2 with 7 intervals. The stimulus sets were arranged so that each set was matched with another, with no overlapping stimuli between them. This way, the unique stimuli for learned rhythms and novel rhythms were balanced across participants. For example, participants who learned set 1 were tested on sets 1 (learned/rescaled) and 2 (novel) during the final experimental session (see Table 1). Stimulus sets 3 and 4 were a second permutation of the 24 rhythms, and were added to eliminate stimulus-specific effects (e.g. if the rhythms in set 1 were unexpectedly easier to reproduce than set 2, the permutations in sets 3 & 4 should balance this issue). Participants were assigned stimulus sets for training consecutively, such that participants 1, 2, 3, & 4 would be trained on sets 1, 2, 3, & 4, respectively.

Table 1: Rhythmic Stimuli

Stimulus Set	*Metric Simple*	*Metric Complex*	*Nonmetric*
Set 1	1 1 1 1 4 3 1	1 4 1 1 3 1 1	1 3.6 1 4 1 1 1
	2 1 1 2 2 3 1	1 1 3 2 2 1 2	1.4 1 1.4 3.6 1.4 1 1
	1 1 2 3 1 4	1 2 2 1 4 2	1.4 1 4 1.4 1.4 1
	2 2 1 3 3 1	2 3 1 1 2 3	1 3.6 1.4 3.6 1.4 1
Set 2	2 1 1 3 1 1 3	2 3 3 1 1 1 1	3.6 1 1 3.6 1 1.4 1
	3 1 4 1 1 1 1	2 1 4 1 2 1 1	3.6 1.4 1.4 1 1 1 1.4
	3 1 2 2 1 3	3 2 3 2 1 1	1.4 1.4 1 1.4 4 1
	3 1 1 3 2 2	4 1 2 2 1 2	4 1.4 1 3.6 1 1
Set 3	1 1 1 1 4 3 1	2 1 4 1 2 1 1	1 3.6 1 4 1 1 1
	2 1 1 3 1 1 3	1 1 3 2 2 1 2	3.6 1 1 3.6 1 1.4 1
	1 1 2 3 1 4	1 2 2 1 4 2	1 3.6 1.4 3.6 1.4 1
	3 1 1 3 2 2	3 2 3 2 1 1	1.4 1.4 1 1.4 4 1
Set 4	2 1 1 2 2 3 1	2 3 3 1 1 1 1	3.6 1.4 1.4 1 1 1 1.4
	3 1 4 1 1 1 1	1 4 1 1 3 1 1	1.4 1 1.4 3.6 1.4 1 1
	2 2 1 3 3 1	4 1 2 2 1 2	4 1.4 1 3.6 1 1
	3 1 2 2 1 3	2 3 1 1 2 3	1.4 1 4 1.4 1.4 1

Note: In training, 1 = 250ms. In rescaling, 1 = 210, 230, 270, & 290ms. All other intervals are multiples of the selected base unit.

2.3 Procedure

The experiment had 5 sessions, each separated by at least 24 hours. In the first 4 sessions (Training), participants learned to reproduce and synchronize with 12 unique rhythms. In the 5th session (Test), participants were tested on their ability to reproduce the 12 trained rhythms at the learned, slower, and faster rates. At this time they were also tested on 12 novel rhythms that were not heard before.

Prior to starting the experiment, participants read a letter of information and signed informed consent. Participants were told that they would learn to tap 12 rhythms over the course of 4 training sessions. They were also informed that they would be tested on rhythms that they would recognize from training, and others that they may not recognize

from the study, in the 5th session.

On each day of Training, participants underwent 2 blocks of the Rhythm Reproduction task, separated by 1 block of Rhythm Synchronization (tasks are described below) (Figure 2). Before each block, participants were reminded of the task requirements. On the first day, participants also performed the Beat Alignment Test (BAT), and preferred tempo tapping task. On the last day (the Test phase), participants performed the Rescaling Reproduction task followed by a short music experience questionnaire. All participants performed the sessions seated at a desk with a laptop computer. All stimuli for the experiment were delivered using noise-reducing headphones. After the final session, participants were given a debriefing form. The purpose of the experiment was reiterated orally.

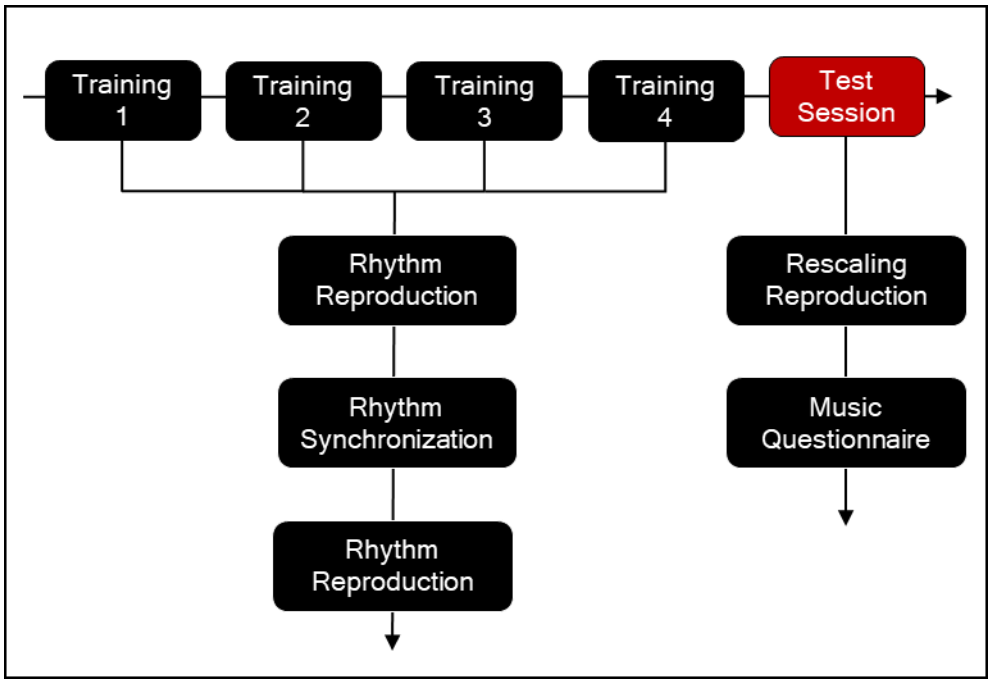

Figure 2: Procedure Flow Chart.

2.3.1 Beat Alignment Test (BAT)

The Beat Alignment Test (BAT; Iverson & Patel, 2008) measured participants' ability to produce and perceive a beat when listening to short music clips. In the production test, participants listened to music clips and tapped the beat on a computer key in time with the beat that they perceived. After each trial, participants rated their familiarity with the stimulus.

In the beat perception test, participants listened to the same music clips, but this time paired with an isochronous series of tones that was timed to be either on or off the beat. Participants decided whether the tone was on or off the beat, and indicated via button press as soon as they knew their response. BAT production and perception tests were presented in the same order for each participant.

2.3.2 Preferred Tempo

Participants tapped on a contact microphone at a steady pace that felt most comfortable to them. Responses were recorded for 30 seconds using Audacity software. Data from the preferred tempo task were not analyzed for the current experiment.

2.3.3 Rhythm Reproduction (Training)

Rhythm Reproduction required participants to listen to a rhythm, and then reproduce the rhythm by tapping a key on a computer keyboard. On each day of training, two blocks of the Rhythm Reproduction task were performed. In a block, each unique rhythm stimulus was attempted on two consecutive trials, for a total 24 trials per block.

On each trial, the rhythm was presented twice, with a 1000 ms silent inter-stimulus interval. Participants viewed a black screen with white words "first time" and "second

time" appearing the first and second times the rhythm was presented. After the second presentation, the screen turned red, with the words "tap back", indicating that the participant was to reproduce the rhythm that they just heard. The response window duration was 4000ms longer than the stimulus duration. Participants were instructed to use the 'm' key on the computer to reproduce the intervals, and to do so as accurately as possible. If every interval in a rhythm was reproduced within 15% of its target duration (e.g. a 250 ms interval was considered correctly reproduced between 212.5 ms and 287.5 ms), participants received feedback that the trial was correct. If there were too many or few taps, or if any of the intervals were tapped outside of the 15% window, the feedback indicated an incorrect response.

So as to not discourage participants, the feedback threshold was set at 20% for the first block on the first day of training. All subsequent blocks were set at the 15% threshold. Participants were informed of the threshold before completing each block.

2.3.4 Rhythm Synchronization (Training)

The synchronization task was used to help participants identify tapping errors using tone-by-tone feedback. As participants synchronize taps with the tones, it becomes clear which intervals are being reproduced too short or too long during rhythm reproduction. Pilot testing showed that the synchronization task helped improve performance on the rhythm reproduction task.

During the synchronization task, participants tapped along with (synchronized to) the tone onsets in the rhythm. Before starting the task, onscreen instructions were read by the participant. The researcher also explained the task orally, and reminded participants to

notice when they tapped in relation to the onset of the tones. Each block of rhythm synchronization started with 1 practice trial. The practice stimulus was not used elsewhere in the experiment.

For each trial, one rhythm was repeated 25 times, with 290ms of silence between repetitions. The silent gaps were timed such that the rhythm repetitions did not start on the beat. Participants initiated the start of a trial by pressing the space bar on a computer. A black screen with white numbers displayed a countdown from 3 (“3”, “2”, “1”) before stimulus presentation began. During stimulus presentation, the screen read “Tap along with the tones.”

To ensure recorded response times and stimulus onset times were not misaligned by computer timing lags, the synchronization task used an external recording setup. A Steinberg UR22 mk II soundcard was used to simultaneously record both stimulus presentation and responses. To do this, participants tapped on a contact microphone, which inputted audio signal to the right channel of the soundcard. The stimulus output was looped from the source (computer) into the left input channel of the soundcard. During the task, right and left channel inputs were recorded simultaneously using Audacity software. The stimulus onset and tap times were then computed directly from the waveforms created in Audacity (stimulus/response recording procedure adapted from Jacoby & McDermott, 2017).

2.3.5 Rescaling Reproduction (Test)

Rescaling Reproduction was used in the final test phase of the experiment (session 5; Figure 2). The trials of this task were identical to Rhythm Reproduction. In Rescaling

Reproduction, participants were tested on 48 stimuli. This included 12 trained, 12 novel, and 24 rescaled stimuli. Rescaled stimuli were made up of the same relative ratios as the 12 training rhythms, but were adjusted to be slower-than-trained, and faster-than-trained rates. The base unit (1 intervals; Table 1) for the training tempo was 250ms. In the faster condition, the base unit was shortened by 8% (230ms), in the slower condition, the base unit was elongated by 8% (270ms).

A portion of the participants performed more extreme rescaling (16% faster and slower) in addition to the original 8% rescaling conditions. As the extra rescaling required a longer testing session, the extra rescaling task allowed for a break halfway through the session.

Chapter 3

3 Results

3.1 Analysis

Rhythm Reproduction and Rescaling Reproduction performance was analyzed by comparing the durations between participant keypresses (reproduced intervals), to the durations between tone onsets in the stimuli (stimulus intervals). For each interval in a rhythm, proportional timing error in milliseconds was calculated by subtracting the stimulus interval from the corresponding reproduced interval, and then dividing by the duration of the stimulus interval. Thus, perfect reproduction would be 0 error. The absolute value of this proportional error was then averaged across all intervals within a trial, to give one average proportional error value per trial.

Trials with the incorrect number of taps were excluded from the average error analysis, as it is not clear which taps were intended to correspond to which stimulus interval. To account for differing trial counts between subjects that resulted from this exclusion, reproduction ability was additionally assessed by analyzing the proportion of trials excluded owing to incorrect number of taps. This analysis revealed a similar pattern of results across conditions as the proportional error analysis did (e.g., conditions with higher proportional error also tended to have higher numbers of excluded trials), therefore the excluded trial data are only reported in Appendix A.

3.2 Rhythm Reproduction (Training)

Rhythm Reproduction data are shown in Figure 3. A one-way repeated measures ANOVA was conducted on average proportional error to assess differences related to

beat strength (MS, MC, NM) in the last session of training (averaged across 2 blocks in the 4th training session). A significant main effect of beat strength was found, $F(2, 50) = 14.70$, $p < .001$, $\eta_p^2 = .563$. Follow-up paired sample t-tests revealed that MS rhythms ($M = .11$, $SD = .063$) were performed with significantly less error than both MC rhythms ($M = .15$, $SD = .095$), $t(25) = -4.31$, $p < .001$, and NM rhythms ($M = .16$, $SD = .069$), $t(25) = -5.04$, $p < .001$. MC rhythms and NM rhythms were not significantly different at the end of training, $t(25) = -1.31$, $p = .20$.

Differences in the pattern of improvement over training sessions between beat strength conditions could indicate that different strategies were used to learn different rhythm types. To quantify learning trends, a linear function was fit to the average proportional error for each metric condition across the 8 rhythm reproduction blocks. The resulting linear slope values were then used in a one-way repeated measures ANOVA to measure differences in the learning rate for MS, MC, and NM rhythms. This analysis revealed no significant differences in rate of learning based on beat strength, $F(2,50) = .078$, $p = .93$, suggesting that beat strength did not alter how quickly participants improved performance. Thus, the differences in reproduction accuracy between levels of beat strength for the training phase appears to indicate a stable timing benefit related to the beat.

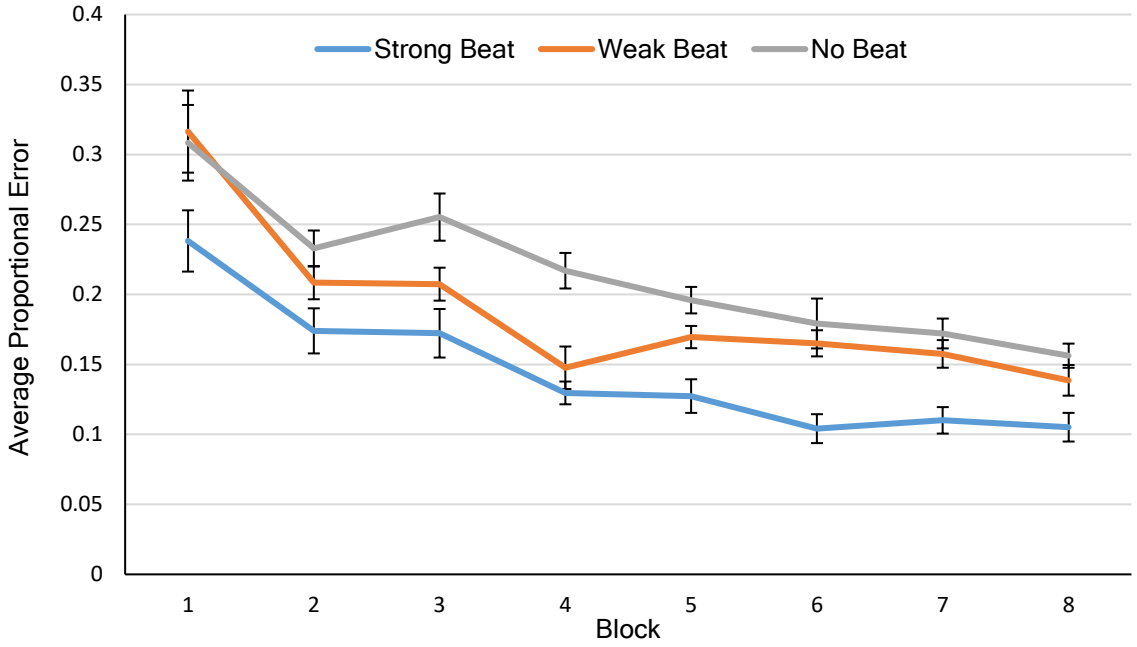

Figure 3. Average Proportional Error across 8 Training Blocks. Error bars depict within-subject standard error (Loftus & Masson, 1994).

3.3 Rescaling Reproduction (Test)

3.3.1 Proportional Error

Proportional error in the final test session was evaluated with a 3 (beat strength; MS, MC, NM) × 4 (rescaling; learned, slower, faster, novel) repeated measures ANOVA (Figure 3). Greenhouse-Geisser adjustment was used where sphericity violation occurred. Significant main effects were found for both beat strength, $F(2, 50) = 22.98$, $p < .001$, $\eta_p^2 = .479$, and rescaling conditions $F(1.60, 39.94) = 18.20$, $p < .001$, $\eta_p^2 = .421$. The beat strength by rescaling interaction was not significant, $F(3.17, 79.12) = 1.17$, $p = .33$ (Figure 4).

Follow-up paired t-tests were used to determine which differences led to the main effects. Post-hoc analyses of the beat strength main effect revealed that MS rhythms ($M = .12$, SD

= .076) were performed with lower average proportional error than both MC rhythms (*M* = .16, *SD* = .093), *t*(26) = -4.71, *p* < .001, and NM rhythms (*M* = .20, *SD* = .11), *t*(26) = -5.96, *p* < .001. Additionally, MC rhythms exhibited significantly lower average proportional error than NM rhythms *t*(26) = -3.04, *p* = .006.

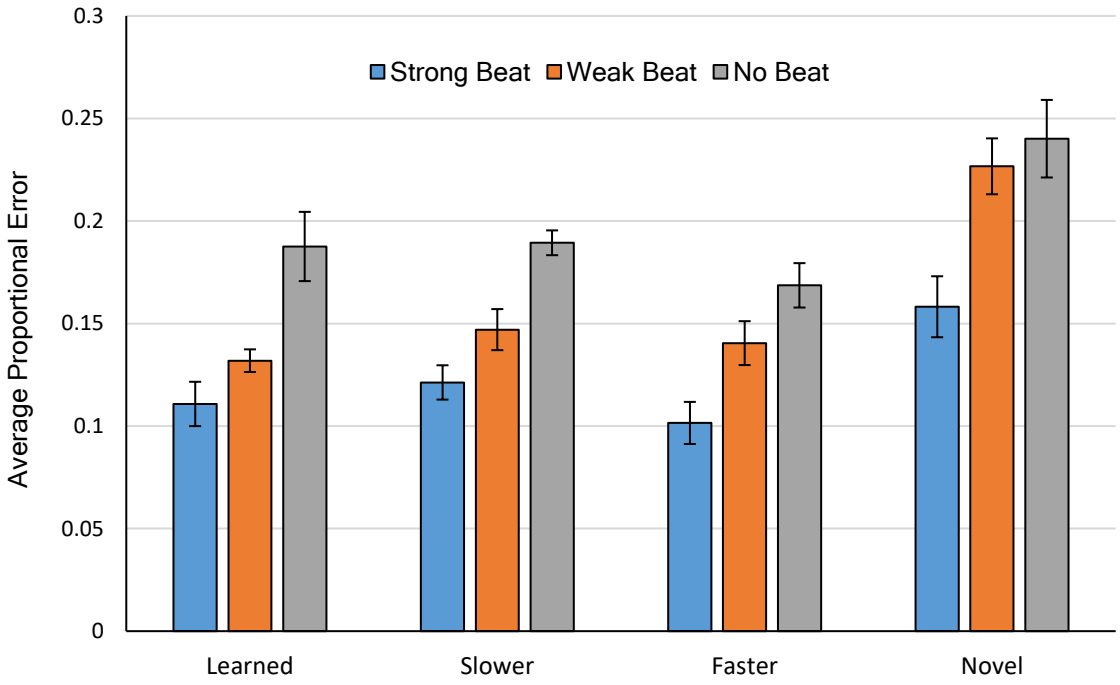

Figure 4. Average Proportional Error during Rescaling Reproduction Test Session. Error bars depict within-subject standard error (Loftus & Masson, 1994).

Follow-up paired t-tests for the rescaling main effect showed no significant differences in performance between learned (*M* = .14, *SD* = .092) and either faster (*M* = .14, *SD* = .081), *t*(25) = .953, *p* = .35 or slower (*M* = .15, *SD* = .092), *t*(25) = -.991, *p* = .33 rhythms. Performance also did not differ between faster and slower rhythms, *t*(25) = 1.994, *p* = .057. However, performance in the novel condition (*M* = .21, *SD* = .11) was significantly

worse than in learned, $t(25) = -4.49$, $p < .001$, slower, $t(25) = -5.93$, $p < .001$, and faster conditions $t(25) = -4.86$, $p < .001$.

3.3.1.1 Influence of Music Training and Beat Perception Ability

As beat perception ability and musical training can covary with rhythm reproduction performance, the above ANOVA was also conducted with either BAT perception score or years of musical training added as a covariate (a total of 2 independent ANCOVAs were conducted, each with just 1 of these covariates included). However, as neither of the covariate main effects were significant, and neither covariate significantly interacted with the beat strength or rescaling factors, the results of the ANCOVAs are not reported.

3.3.1.2 Extra Rescaling

A 3 (beat strength; MS, MC, NM) × 6 (rescaling; learned, slower, extra slow, faster, extra fast, novel) repeated measures ANOVA was conducted on proportional error using data from the 12 participants who performed rescaling of the 16% rate-changed stimuli in addition to the 8% rate-changed stimuli (data represented in Appendix B). As in previous analyses, significant main effects were observed for both beat strength, $F(2,22) = 11.77$, $p < .001$, $\eta_p^2 = .517$, and rescaling conditions, $F(5,52) = 4.17$, $p = .003$, $\eta_p^2 = .275$. A significant interaction was not observed $F(10,110) = 1.82$, $p = .066$, $\eta_p^2 = .142$.

Follow-up paired t-tests were conducted to evaluate the main effects. For the beat strength main effect, performance on MS rhythms ($M = .099$, $SD = .057$) was not significantly different from MC rhythms ($M = .11$, $SD = .045$), $t(11) = -2.03$, $p = .068$, but had significantly less error than NM rhythms ($M = .15$, $SD = .040$), $t(11) = -3.62$, $p =$

.004. Additionally, performance on MC rhythms had significantly less error than NM rhythms, $t(11) = -3.55$, $p = .005$.

For the rescaling main effect, learned rhythms ($M = .10$, $SD = .039$) were performed with significantly less error than slower rhythms ($M = .11$, $SD = .048$), $t(11) = -2.47$, $p = .031$, extra slow rhythms ($M = .12$, $SD = .038$), $t(11) = -2.27$, $p = .045$, and novel rhythms ($M = .15$, $SD = .040$), $t(11) = -5.19$, $p < .001$. Faster rhythms ($M = .11$, $SD = .061$) were performed with significantly less error than novel rhythms, $t(11) = -2.79$, $p = .018$. Extra slow rhythms were performed with significantly less error than novel rhythms, $t(11) = -4.83$, $p = .001$. No other comparisons were significant (ps > .13). In general, performance did not worsen with extra rescaling.

3.3.2 Ratio Analysis

Proportional error only measures the difference between response times and a target duration, and does not consider the reproduced between-interval relationships. Thus, if participants spontaneously rescale their reproduced rhythms (e.g., reproducing them faster or slower than presented), but do so accurately (maintaining the ratio relationships between intervals) the reproductions will still appear incorrect in a comparison of response and target timing in milliseconds. To examine whether accuracy differed across rhythm conditions when spontaneous rescaling was not penalized, we analyzed the average reproduced ratios in each rhythm, scaled relative to the overall duration of the reproduced rhythm, during the rescaling task. It is important to look at timing accuracy on the interval level (in addition to the whole rhythm analysis above) because of the influence of different interval types in past literature. For example, previous rescaling analysis found differences in rescaling ability for integer and non-integer sequences

(Collier & Wright, 1995). As the NM rhythms contain both integer and non-integer ratios, it is possible that reproduction accuracy and rescaling accuracy is altered by interval type.

For the ratio analysis, each reproduced interval was divided by the total duration of reproduction in a trial (i.e. the time from the first tap to the final tap). Each resulting fraction of the total duration was then multiplied by the total number of base units in the target rhythm (e.g., the rhythm 43122 would have 12 base units), thus converting the response duration fractions (in milliseconds) into ratio units (e.g., 1, 2, 3, 4). In a trial, ratios for each unique interval type were averaged. By this calculation, perfect reproduction of ratios would result in 1, 2, 3, and 4 ratios for the MS and MC rhythms, and 1, 1.4, 3.6, and 4 for the NM rhythms. For example, if a rhythm had intervals 1000 750 250 500 500, but was reproduced faster, say as 800 600 200 400 400, then these steps would yield values of 4,3,1,2,2. Signed proportional error for the reproduced ratios was then calculated by subtracting the ideal performance from the average reproduced ratios on each trial, and then dividing by the ideal ratio, yielding the proportion error of the ratio. Thus, negative-signed error indicates a shortening of that interval ratio (relative to the duration of the entire rhythm), and positive error indicates a lengthening of the interval. Perfect reproduction would result in 0 error.

A 3 (beat strength; MS, MC, NM) × 4 (rescaling; learned, slower, faster, novel) × 4 (interval; 1,2,3,4; for NM: 2 = 1.4, 3 = 3.6) repeated measures ANOVA was conducted on reproduced ratio error values. This revealed significant main effects of beat strength, $F(1.59, 39.70) = 14.24$, $p < .001$, $\eta_p^2 = .363$, and interval, $F(1.58, 39.40) = 35.49$, $p < .001$, $\eta_p^2 = .587$. The main effect of rescaling was not significant, $F(2.17, 54.34) = 1.11$, p

= .34. Significant interactions were found between beat strength and interval, $F(3.23, 80.85) = 10.59$, $p < .001$, $\eta_p^2 = .297$, and between rescaling and interval, $F(4.22,105.38) = 3.51$, $p = .009$, $\eta_p^2 = .123$ (Figure 5).

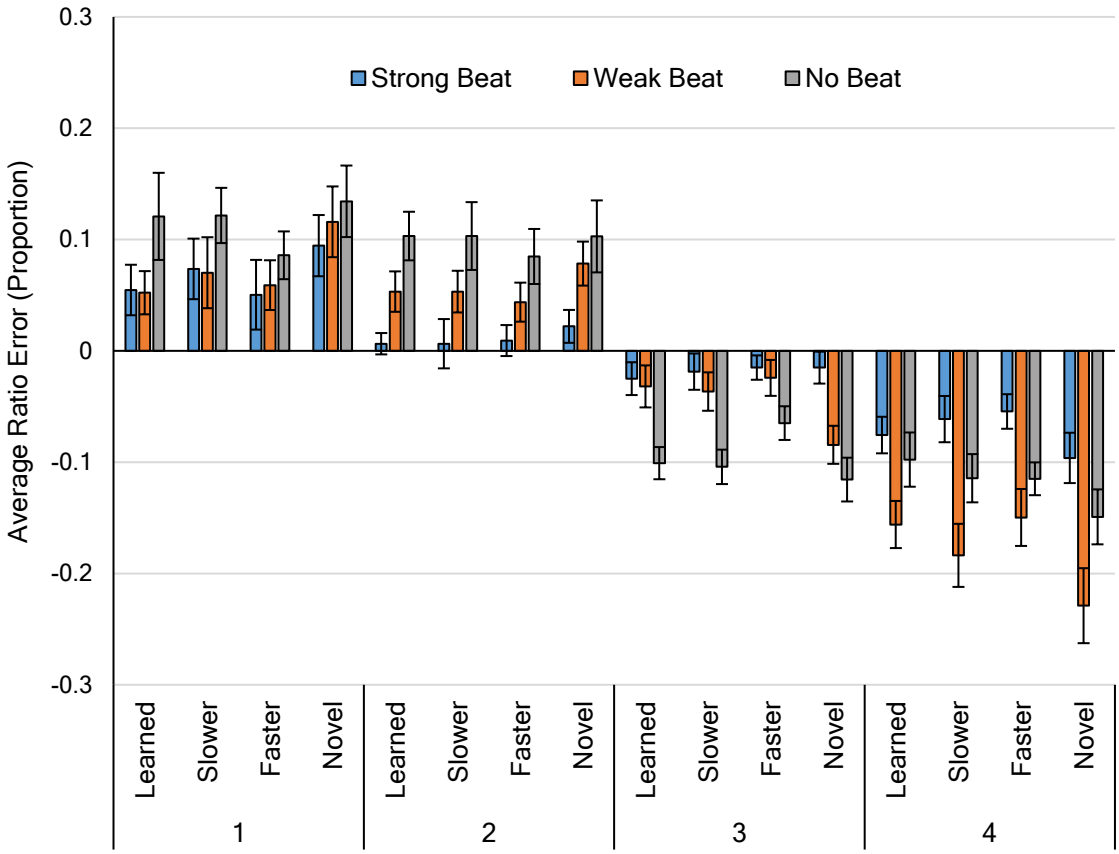

Figure 5. Average Proportional Error for Reproduced Ratios. For NM rhythms, 2 and 3 intervals are 1.4 and 3.6. Values further from 0 represent greater error. Error bars depict within-subject standard error (Loftus & Masson, 1994).

Follow-up paired t-tests were conducted to evaluate the main effects. Performance error for ratios was collapsed across interval and rescaling conditions to examine the beat strength main effect. On average, MS intervals (M = -.0025, SD = .0081), were truncated significantly less (closer to 0 performance error) than MC intervals (M = -.024, SD = .023), $t(25) = 4.27$, $p < .001$, but were not significantly different from NM intervals (M =

-.0023, *SD* = .013), *t*(25) = -.084, *p* = .93. MC intervals were truncated significantly more than NM intervals, *t*(25) = -4.015, *p* < .001.

The main effect for interval was calculated by comparing the average ratio error collapsed across beat strength and rescaling conditions for each interval. Performance on 1 intervals (*M* = .086, *SD* = .90) was not significantly different from 2 intervals (*M* = .0525, *SD* = .057), *t*(26) = 1.66, *p* = .11, but were significantly longer than 3 intervals (*M* = -.053, *SD* = .056), *t*(26) = 5.012, *p* < .001, and 4 intervals (*M* = -12, *SD* = .079), *t*(26) = 6.78, *p* < .001. Similarly, the 2 intervals were significantly longer than the 3 intervals, *t*(26) = 5.56, *p* < .001, and 4 intervals, *t*(26) = 7.31, *p* < .001. Finally, the 3 intervals were truncated significantly less than the 4 intervals, *t*(26) = 8.62, *p* <.001. Notably, differences between the short (1 and 2) intervals and long (3 and 4) intervals were driven by different directions of error (lengthening vs. shortening). That is, shorter intervals were reproduced as longer than their respective target ratios, and longer intervals were reproduced as shorter than their respective target ratios.

Moving next to the beat strength by interval interaction, average ratio error was collapsed across rescaling conditions, and paired-sample t-tests were conducted to compare ratio error across levels of beat strength (MS, MC, NM) within each interval condition (1, 2, 3, 4). On average, MS 1 intervals (*M* = 0.068, *SD* = 0.10) were significantly less elongated (closer to 0 error) than NM 1 intervals (*M* = .12, *SD* = .12), *t*(25) = -2.66, *p* = 0.014. MC 1 intervals (*M* = .074, *SD* = .11) did not significantly differ from MS or NM 1 intervals (*p*s > .11). MS 2 intervals (*M* = .012, *SD* = .06) were truncated significantly less than MC 2 intervals (*M* = .055, *SD* = .055), *t*(25) = -4.03, *p* < .001 , and NM 2 intervals (*M* = .091, *SD* = .11), *t*(25) = -3.30, *p* = .003. MC 2 intervals and NM 2 intervals were not

significantly different, $t(26) = -1.80$, $p = .083$. MS and MC 3 intervals ($M = -.0184$, $SD = .046$) were not significantly different ($M = -.044$, $SD = .077$), $t(25) = 1.96$, $p = .061$. MS 3 intervals were truncated significantly less (closer to 0 error) than NM 3 intervals ($M = -.096$, $SD = .073$), $t(25) = 9.04$, $p < .001$. MC 3 intervals were truncated less than NM 3 intervals, $t(25) = 3.64$, $p = .001$. MS 4 intervals ($M = -.072$, $SD = .075$) were truncated significantly less than both MC 4 intervals ($M = -.18$, $SD = .12$), $t(25) = 5.96$, $p < .001$, and NM 4 intervals ($M = -.12$, $SD = .081$), $t(25) = 2.93$, $p = .007$. However, MC 4 intervals were truncated significantly more than NM 4 intervals, $t(25) = -3.54$, $p = .002$. In sum, it appears that the short MS intervals were lengthened less than MC and NM intervals, and the long MS intervals were shortened less than the MC and NM rhythms. MC and NM intervals only differed on the long intervals (3 & 4), but the direction of this difference did not systematically depend on beat strength.

Finally, the rescaling by interval interaction was explored by collapsing ratio error scores across beat strength conditions, and conducting paired-samples t-tests between rescaling conditions within each interval. Slow 1 intervals ($M = .089$, $SD = .098$) and novel 1 intervals ($M = .11$, $SD = .11$) were elongated significantly more than fast 1 intervals ($M = .066$, $SD = .10$), $t(25) = 2.14$, $p = .043$; $t(25) = -2.54$, $p = .018$. Fast 3 intervals ($M = -.035$, $SD = .062$) were significantly less truncated than learned 3 intervals ($M = -.053$, $SD = .066$), $t(25) = 2.40$, $p = .024$, slow 3 intervals ($M = -.053$, $SD = .064$), $t(25) = 2.73$, $p = .012$, and novel 3 intervals ($M = -.072$, $SD = .056$), $t(25) = -4.34$, $p < .001$. Learned 4 intervals ($M = -.11$, $SD = .086$) and fast 4 intervals ($M = -.11$, $SD = .080$) were significantly less truncated than novel 4 intervals ($M = -.16$, $SD = .11$), $t(25) = 2.86$, $p = .008$; $t(25) = 2.97$, $p < .001$. No other post-hoc comparisons for this interaction were

significant (all *p*s > .06). In general, short intervals in the fast condition were not lengthened as much as short slow and novel intervals, and long intervals in the learned and fast conditions were less truncated than long intervals for the novel condition.

3.3.3 Correlation with Training Performance

To investigate the relationship between Rhythm Reproduction performance during training and performance on the Rescaling Reproduction task, proportional error for the final training session (performance averaged across the 2 blocks on the 4th day of training) was correlated across participants with proportional error for the learned rate, rescaled rates (averaged across slower and faster conditions), novel stimuli during Rescaling Reproduction, and the first day of training (averaged across 2 blocks). Significant Spearman correlations were found between final training session performance and rescaling reproduction performance for all beat strength conditions (see Table 2).

Table 2. Correlations with Final Training Session Performance error and performance on the Rescaling and Novel conditions in the Rescaling Reproduction task.

	Conditions			
	Learned	Rescaled	Novel	First Session
Metric Simple	$r_s = .69$ $p < .001$	$r_s = .63$ $p = .001$	$r_s = .78$ $p < .001$	$r_s = .68$ $p < .001$
Metric Complex	$r_s = .66$ $p < .001$	$r_s = .72$ $p < .001$	$r_s = .45$ $p = .023$	$r_s = .42$ $p = .023$
Non-Metric	$r_s = .60$ $p = .001$	$r_s = .64$ $p < .001$	$r_s = .42$ $p = .033$	$r_s = .42$ $p = .035$

Altogether, these correlations suggest that performance on the final day of training predicted performance in the Rescaling Reproduction task for all beat strength conditions. Strong relationships (i.e., $r > .6$) for learned and rescaled conditions indicate that participants who performed well during training also performed well on the same rhythms in the final Rescaling Reproduction task, regardless of rate changes. For MC and NM rhythms, relatively weaker correlations for performance on the final day of training with performance on the first day of training, and performance on the final day of training with performance on novel rhythms during the Rescaling Reproduction task may reveal that familiarity with the stimuli was important for predicting performance. However, for the MS rhythms, performance during the final training session predicted Rescaling Reproduction performance for both familiar (i.e., during rescaling and learned conditions) and unfamiliar stimuli (i.e., novel and first training session).

Chapter 4

4 Discussion

Research in rhythm and timing suggests that the presence of a beat in acoustic rhythms elicits behavioural advantages in rhythm reproduction. Behavioural advantages may arise from the beat structure across a rhythm, which allows for interval durations to be encoded relative to the beat, rather than encoding a rhythm as a series of independent durations. However, as the everyday human environment is rich with regularity, such as in music, an equally plausible explanation for beat-based advantages is a general familiarity with strong-beat rhythms. Thus, previous research in beat perception may be confounded by the discrepant familiarity between rhythms with a strong beat and irregular rhythms that do not have a beat. The current study was designed to probe whether equally familiar acoustic rhythms were encoded relative to beat strength, or whether timing performance is dependent on familiarity with a rhythm, regardless of beat strength. By familiarizing participants with strong-, weak-, and non-beat rhythms, we expected to see differences in rescaling accuracy, an ability known to be possible for beat-based music, that would be sensitive to either beat strength, or familiarity. Generally, the results did not conclusively show that timing performance depends solely on either beat strength or familiarity. However, there is evidence that both beat strength and familiarity improve timing performance independently.

The following discussion details the current findings, how the findings fit with previous research, limitations to the study, and proposed future directions to continue investigating the encoding and mental representations of rhythm.

4.1 Current Findings

Over 4 days of training, participants improved performance for rhythms in strong-, weak- and non-beat conditions. The goal of the training period was to improve performance such that beat and non-beat rhythms could be reproduced at similar accuracy. However, despite equal exposure to and practice on all rhythms, weak- and non-beat rhythms were not performed as accurately as strong-beat rhythms by the end of training. The analysis of slope across the 4 training days revealed that the rate of learning was not significantly different between rhythmic conditions. Thus, the difference in accuracy at the end of training was similar to the difference in accuracy at the beginning of training, perhaps indicating a benefit of beat strength that is independent from exposure-based benefits.

On the final test (Rescaling Reproduction), the effect of beat strength remained: Strong-beat rhythms were reproduced most accurately, followed by weak-beat rhythms, and non-beat rhythms were reproduced at the poorest accuracy overall. Surprisingly, rescaling accuracy was not sensitive to beat presence. Reproduction accuracy for trained strong-, weak-, and non-beat rhythms did not alter depending on rate. Moreover, the learned (same rate) and rescaled (faster/slower rate) versions of the trained rhythms were both performed more accurately than the novel rhythms, suggesting that rescaling did not compromise the learning gained from the training period.

The analysis of reproduced ratios indicates a general truncating of longer intervals (i.e. 3, 3.6, 4), and better precision on shorter intervals (i.e. 1, 1.4, 2). Consistent with previous work, truncation of 3 and 4 intervals was less severe for strong-beat rhythms (Grahn & Brett, 2007), suggesting that beat presence aids in reproducing longer intervals. This beat-based benefit may be due to the structure provided by the beat, which allows

participants to encode a smaller unit of time (i.e. a beat unit), rather than encoding and reproducing a unique long duration. For example, a 4 interval may be more accurately reproduced if it is encoded as 2 shorter beat units, for which reproduction is shown to be more accurate. However, when it is difficult to detect a beat, performance accuracy may reflect the difficulty in estimating longer units of time.

Some have suggested that non-integer ratios elicit greater error because they are systematically regularized to nearby integer-related intervals (e.g., a 1.4 interval may be reproduced as a 2 interval) (Collier & Wright, 1995; Jacoby & McDermott, 2017). Though the 1.4 and 3.6 intervals in the current study do appear to approach integer-related intervals (1.4 is elongated towards 2, and 3.6 is truncated towards 3), this pattern of error is not reliably different from integer-ratio error for similar durations. For example, error on the 1.4 ratios were not significantly different from the MC 2 ratio error, and the longer intervals in strong and weak-beat rhythms are truncated to a similar degree as the long intervals (3.6 and 4) in non-beat rhythms (see Figure 5). Therefore, it is more likely that participants have difficulty prolonging responses for long durations or have a limited ability to encode long durations, and the greater truncation for 3.6 intervals is due to its longer absolute duration compared to the 3 interval. A general difficulty with long intervals could explain the slight improvement on 3 and 4 intervals in the faster rescaling condition. At faster rates, the absolute durations of intervals become shorter, thus a tendency to truncate intervals, or an inability to encode longer durations, would affect performance on 3, 3.6, and 4 intervals less in this condition.

4.2 Encoding Rhythms Relative to Beat Strength

Pertaining to the original research question, the results do not conclusively show whether rescaling accuracy depends on beat strength, or familiarity. Our hypothesis predicted an interaction between beat strength and rescaling. If rhythms were encoded relative to a beat, rescaled reproduction accuracy for weak- and non-beat rhythms should be worse than non-rescaled reproduction accuracy, perhaps approaching accuracy observed for novel rhythms. Alternatively, if familiarity allows rescaling, reproduction accuracy after training for learned and rescaled rates should be similar across all beat strengths, and should be more accurately reproduced than novel rhythms. However, neither of these expected results were observed. This is likely because the experimental design depended on participants learning all categories of rhythms to an equal accuracy level during training, and this did not happen. Although participants improved on all rhythms, differences in accuracy between different levels of beat strength persisted across training.

The enhanced performance for strong-beat rhythms throughout the experiment may indicate that beat strength independently benefits rhythmic timing regardless of familiarity with the stimuli. Replicating Grahn and Brett (2007), we show that beat strength improves performance, with stronger beat presence eliciting more accurate reproduction. However, the current study is the first to show that beat strength is still beneficial when stimuli are very familiar. Though training improved performance on all rhythm types over time, the amount of familiarity gained from the training phase was not enough to eliminate the beat-based advantage. Though it is possible that 4 training sessions was not sufficient to override the familiarity gained from environmental exposure to strong-beat rhythms, retaining a beat-strength benefit after equal exposure to

stimuli may suggest that beat strength improves timing independently from familiarity. An independent benefit of beat strength is substantiated by strong correlations between performance on the last session of training and performance on novel rhythms with a strong beat. This correlation indicates that the performance on trained strong-beat rhythms predicts performance on strong-beat rhythms that are relatively unfamiliar. Therefore, this relationship likely does not depend on the familiarity gained from the 4 days of training, but may instead depend on the presence of a strong beat. Relatively weaker correlations for rhythms with a weak or no beat between the final training session and novel rhythms reinforce this interpretation by showing that without a strong beat, the timing performance on rhythms at the end of training do not strongly predict performance on unfamiliar rhythms with weak or no beat presence. Therefore the relatively strong relationship between performance on the final training session and unfamiliar rhythms in the strong-beat condition may be indicative of a general performance benefit of beat presence, rather than the familiarity gained from training.

4.3 The Role of Familiarity

Though the current findings suggest that familiar weak- and non-beat rhythms are still not encoded as accurately as familiar strong-beat rhythms, familiarity does appear to play a role in rescaling accuracy. We found no differences between the performance of learned and rescaled rhythms within each beat condition, and all familiar rhythms were reproduced more accurately than novel rhythms of the same beat-strength. Therefore, familiarity gained from training likely allowed for accurate rescaling in the current experimental design. Like the interpretation of beat-based timing benefits, this conclusion is also substantiated by the pattern of correlations for weak- and non-beat rhythms. While

final training performance was highly correlated with rescaling performance in all beat conditions, correlations were weaker between final training performance and novel rhythms with weak or no beat presence, suggesting that the benefits of the training period were important for reproducing familiar rhythms, even at different-from-learned rates. However, for weak- and non-beat rhythms, the performance in training was less predictive of performance on novel rhythms, suggesting that the improved accuracy for learned and rescaled rhythms was due to familiarity with the stimuli. Importantly, this finding is different from performance on the strong-beat rhythms, which is highly correlated regardless of familiarity, perhaps indicating an added benefit of beat presence for this rhythm type. A similar finding was reported by Tillmann et al. (2011) who found that differences in interval timing performance between two different exposure groups were only statistically significant when the task required rescaled reproduction. At the learned rate, performance on the test sequence was relatively similar between groups, and did not depend on the familiarity with the test sequence, but when reproduced faster than the learned rate, participants who were most familiar with the stimulus performed better than the control group (Tillmann et al., 2011). Together with the current findings, it appears that familiarity with rhythms may provide general benefits to some timing-related tasks, but the difference between beat conditions in the current experiment implies that these familiarity-based benefits may occur independently from beat-related timing benefits.

4.4 A Dual Role of Familiarity and Regularity

In agreement with the current findings, timing research outside of beat perception supports a dual role for regularity and familiarity. For example, one study examined

Western infants' ability to discriminate between sequences with ratios of temporal intervals that were either familiar, unfamiliar, or rare in Western music (2:1, 3:2, 7:4; respectively). While the infants generally detected disruptions (measured via novelty preference after habituation) in stimuli for the simple, familiar ratios, only the 5-month-olds, and not 7-month-olds, detected disruptions in the unfamiliar, complex (3:2) ratios. This suggests that the perception of temporal intervals can become biased towards those commonly experienced in the environment—7-month-olds were insensitive to the less common 3:2 ratios than 5-month-olds. However, neither the 5- nor 7-month-old infants detected disruptions in the rare, highly complex (7:4) intervals. As enculturation had less chance to influence 5-month-olds, this finding suggests that there are inherent constraints to temporal perception prior to cultural familiarity, with a preference for simpler interval ratios (Hannon, Soley, & Levine, 2011).

A general preference for simple interval ratios is also apparent in interval reproduction performance. For example, serial binary intervals (1:2:4:8) are reproduced more accurately than non-binary intervals (1:3:5:6), though both types of ratios occur in music (Wu, Westanmo, Zhou, & Pan, 2013). In a study designed to detect a bias toward regularity in interval reproduction, subjects were presented with a sequence of randomly-timed intervals. After reproducing this "seed" sequence by tapping, the stimulus on the following trial would be made up of the response durations on the previous trial. After many iterations, most subjects tended to regularize the original randomly-timed sequences toward integer-ratio intervals, suggesting that sequence timing is biased towards regularity (Jacoby & McDermott, 2017). Interestingly, the study tested North American and native Amazonian people, two cultures with different rhythmic tendencies

in music. Although North American and Amazonian groups have some different preferred patterns of intervals, there is also much overlap in the preferred patterns between groups, with both groups regularizing the intervals into integer ratios (Jacoby & McDermott, 2017). Altogether, this suggests that familiarity through exposure widely influences the perception and reproduction of temporal intervals. However, a general preference for regularity and simple temporal relationships seems to be universal, and may indicate a regularity bias independent from, or in conjunction with, familiarity biases.

4.5 Limitations

A limitation of this experiment is that subjects did not learn all rhythm conditions equally well. One possible contributing factor to this is that feedback during reproduction performance did not provide information on the types of errors participants were making. During rhythm reproduction tasks, participants received binary feedback, and rhythms were considered incorrect when just 1 interval was incorrect, or were performed with the wrong number of taps. We attempted to remedy this problem by using synchronization during the training blocks, during which participants could hear when sounds were occurring, and compare this time to when they were tapping. However, this method requires participants to have the ability to perceive their mistakes. This type of feedback may not have provided enough information to improve timing for the more difficult weak- and non-beat rhythms for all subjects.

An additional explanation for the differences in rhythm learning is that weak- and non-beat rhythms may require more time to learn than strong-beat rhythms. As culture-based biases are present even at 7-months of age (Hannon, et al., 2011), the presumed

unfamiliarity with weak- and non-beat rhythms may not be overridden by just 4 training sessions. Therefore, if the training session was extended, it is possible that performance on the weak- and non-beat rhythms would continue to improve, perhaps to the accuracy of the strong-beat rhythms.

Finally, it is possible that the method of rescaling used in this experiment was not sensitive to differences in encoding strategies. This may explain why our results conflict with previous rescaling studies. Specifically, Collier & Wright (1995) found that only integer-ratio intervals, compared to non-integer ratios, could be rescaled correctly after learning. In the current study, although rhythms with non-integer ratios were generally performed worse than rhythms with only integer ratios, there were no differences in reproduction performance between the learned and rescaled rates of the non-beat rhythms. This suggests that subjects in the current experiment could rescale rhythms containing non-integer ratios. The analysis of interval ratios confirmed that this ability was not driven by the integer-related ratios in non-beat rhythms, as performance on the 1.4 and 3.6 intervals did not consistently differ between learned and rescaled rates.

The discrepancy with Collier & Wright's (1995) findings may be due to differences in the level of difficulty associated with the current task, and that used in their rescaling experiment. Collier & Wright (1995) only gave their subjects the total duration with which they must tap the two target intervals, whereas in the current experiment participants listened to the target rhythm at the target (whether faster, slower, or the same) rate before responding. Thus, participants in the Collier & Wright (1995) study were required to remember the trained intervals, then internally manipulate the intervals to reproduce the rescaled versions. The current study presented the target rescaling

stimulus before each reproduction. Therefore, participants heard the rescaled version of the rhythm, perhaps making the task somewhat easier. Because Collier & Wright's (1995) task was difficult, it may have been prone to cognitive short cuts, such as regularizing non-integer ratios to reduce cognitive load. As cognitive load influences rhythmic production, with higher cognitive demands eliciting poorer timing performance (Baath, Tjostheim, & Lingonblad, 2016), the discrepancy between the current findings and previous literature may be explained by the lighter cognitive load required for the current experiment.

4.6 Future Directions

Future work on the role of familiarity in beat perception could expand on the current findings in a number of ways. First, it is important to explore the possibility that 4 days of training is not sufficient in equalizing familiarity between strong, weak, and no beat rhythms. Therefore, future research should test the length of training needed to equalize performance across all rhythm types, and thus see if equalizing timing performance is possible for various beat strengths. Additionally, future work should consider the type of feedback provided to participants during training experiments. Anecdotally, some participants in the current study suggested that the feedback provided (both binary during rhythm reproduction, and the online feedback during the synchronization task) was not sufficient in identifying their errors. Perhaps a visual interval-by-interval feedback would be more helpful for participants to improve performance.

An additional avenue to explore is the influence of task difficulty on rescaling performance. Here, participants were provided with a target rhythm, and then asked to reproduce through tapping. However, in previous studies (Collier & Wright, 1995)

participants were not provided with a target template, but were required to rescale intervals based on memory. Therefore, research could ask whether the difficulty of the rescaling task matters for reproduction accuracy. This would identify whether cognitive shortcuts (such as regularizing non-integer ratios) only occur when the task is difficult, or when rescaling relies on an internal manipulation of a rhythm, rather than repeating a rhythm that has recently been presented.

Future research investigating the encoded representations of rhythm should seek to pair behavioural findings with neuroscientific measures, such as fMRI. Using a combination of the learning paradigm used in the current study, and neuroimaging techniques previously used to study beat perception (Grahn & Brett, 2007), one can conclude whether the basal ganglia and SMA become more active for rhythms that have a strong beat, or for rhythms that are familiar and predictable. Taking this idea further, multivariate pattern analysis, an analysis of activity patterns in fMRI data, can be used to decode the neural activity associated with beat perception. Thus, future research can ask whether these activity patterns are correlated with strong, weak, and no-beat presence, or if rhythms that are familiar elicit more similar activity patterns, regardless of beat presence.

4.7 Conclusion

Although the current results were not conclusive about the role of beat presence or familiarity for rhythm timing benefits, there is some evidence for independent benefits of beat presence and familiarity on rhythm reproduction. The presence of a strong beat was already known to improve performance on rhythm timing (Grahn & Brett, 2007). However, this experiment is the first to show that improving timing performance through

familiarity (at least to the degree invoked here) does not overcome the benefit of beat presence. Importantly, this finding could hint at a multiple influences on rhythm encoding, where the perception and production of all rhythm types (strong, weak, no beat) are influenced by familiarity, but rhythms with a strong beat, differently from non-beat, are encoded relative to the beat, thus adding an independent beat-based benefit to rhythmic timing.

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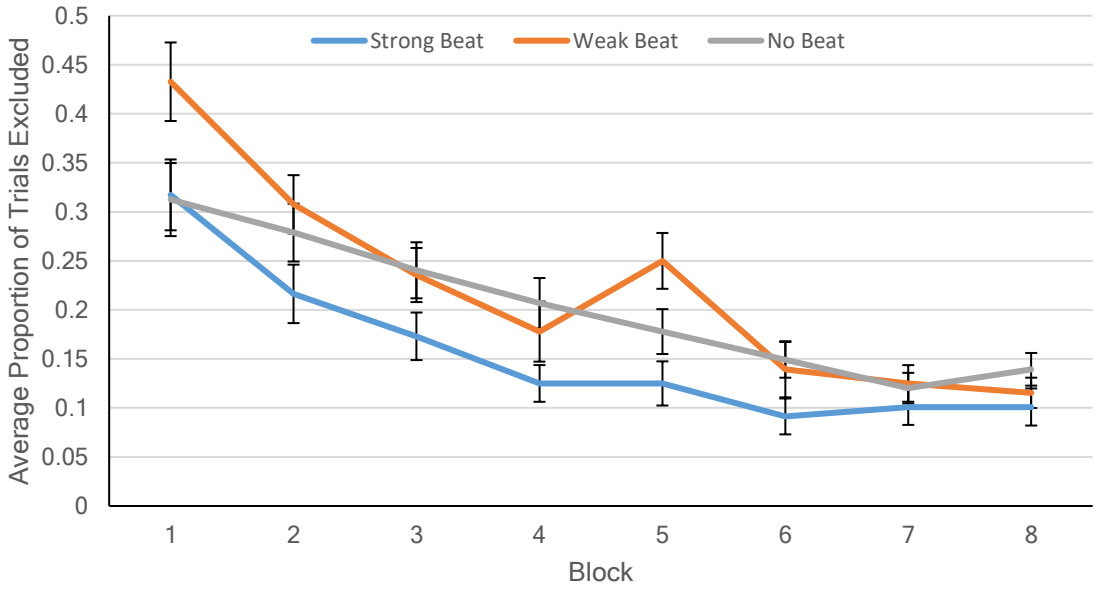
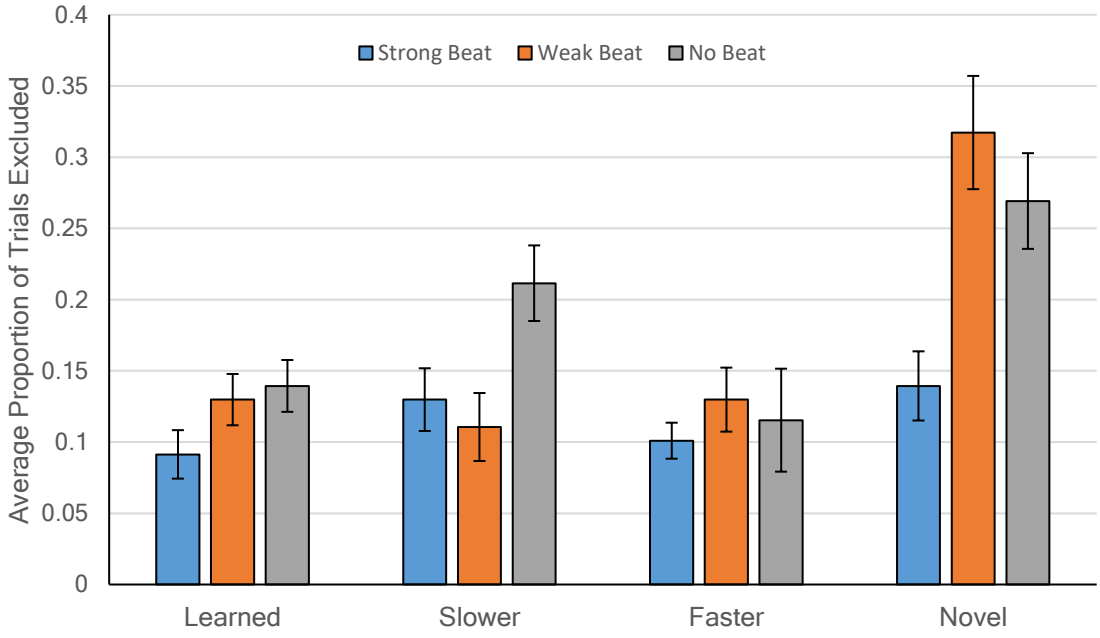
Appendices

Appendix A: Proportion of Trials Excluded from Analysis.

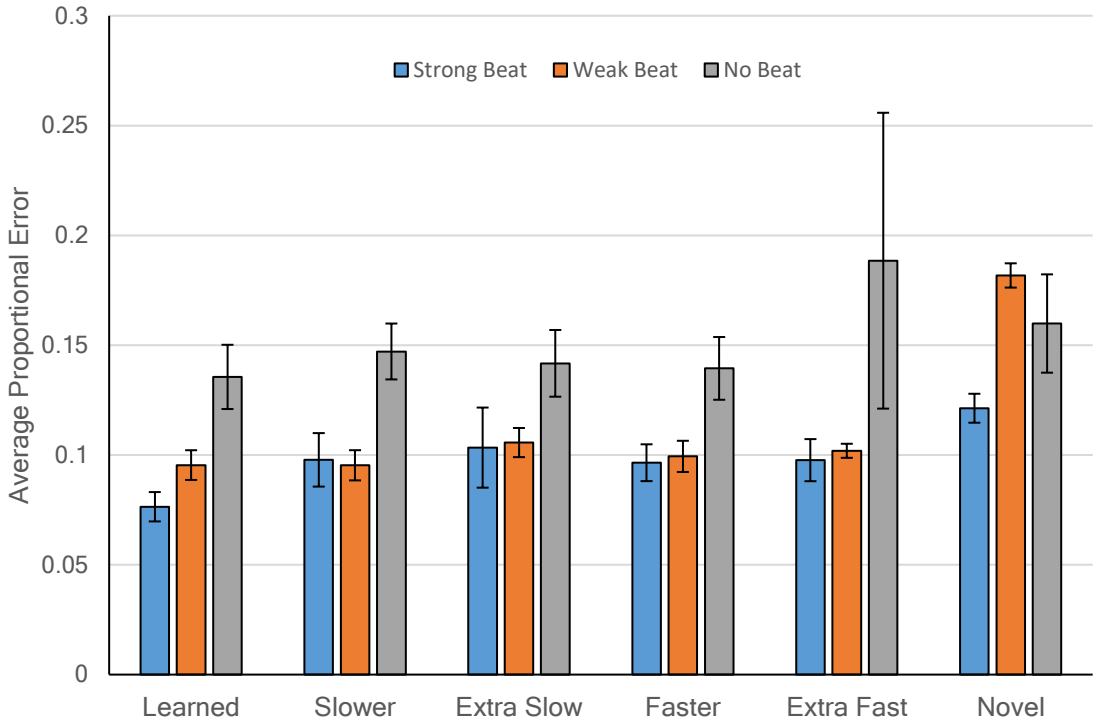
Trials were excluded for having the wrong number of taps. The data indicate a similar, less sensitive measure of response accuracy.



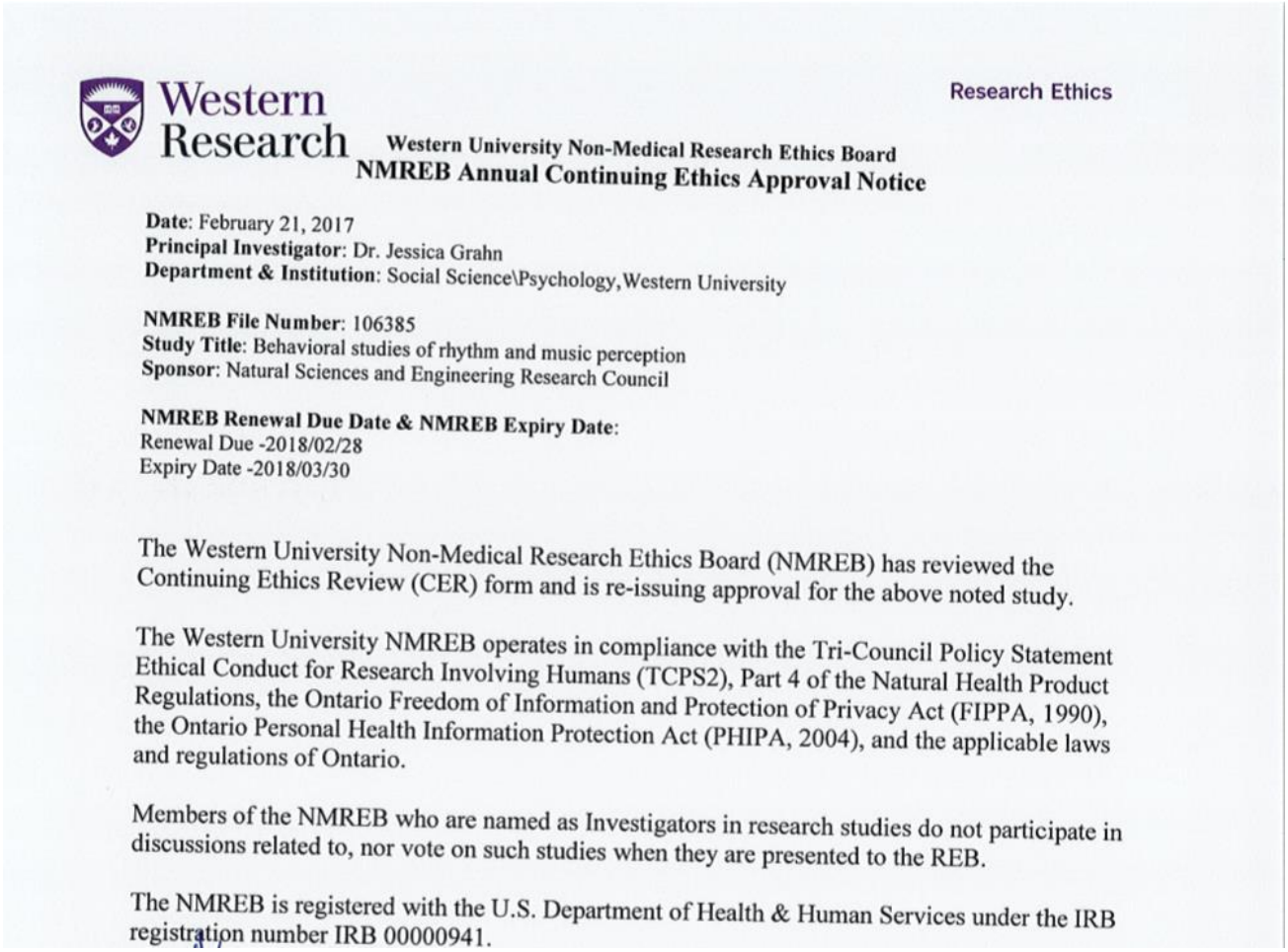


Appendix B: Extra Rescaling Data.

Data from the 12 participants who completed the 16% rescaling condition.



Appendix C: Ethics Approval.



Western Research

Research Ethics

Western University Non-Medical Research Ethics Board
NMREB Annual Continuing Ethics Approval Notice

Date: February 21, 2017
Principal Investigator: Dr. Jessica Grahn
Department & Institution: Social Science\Psychology, Western University

NMREB File Number: 106385
Study Title: Behavioral studies of rhythm and music perception
Sponsor: Natural Sciences and Engineering Research Council

NMREB Renewal Due Date & NMREB Expiry Date:
Renewal Due -2018/02/28
Expiry Date -2018/03/30

The Western University Non-Medical Research Ethics Board (NMREB) has reviewed the Continuing Ethics Review (CER) form and is re-issuing approval for the above noted study.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), Part 4 of the Natural Health Product Regulations, the Ontario Freedom of Information and Protection of Privacy Act (FIPPA, 1990), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario.

Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB.

The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Curriculum Vitae

Joshua D. Hoddinott

Education

9/2017 – Current:	Master of Science, Neuroscience Program
	University of Western Ontario
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1/2012 – 12/2015:	Bachelor of Arts (Honors), Psychology
	Memorial University of Newfoundland, Grenfell Campus
	Corner Brook, NL

Graduate Coursework

9/2016 – 12/2016:	PSYCH 9223A, Neuroimaging in Psychology.
1/2017 – 4/2018:	NEURO 9500B, Principles of Neuroscience.
1/2018 – 4/2018:	COMPSCI/STATS 9869B, Analysis of Brain Imaging Data.
9/2016 – Current:	NEURO 9510Y, Graduate Seminar.

Research

Krachun, C., Wilson, M., & Hoddinott, J. (2018). No pets allowed: Landlord attitudes towards pets in a small Canadian city. *Manuscript Pending Revisions*.

Conference Attendance

Methods Proposal: The Role of Predictability in Beat Perception (Hoddinott, J.). Symposium on Timing and Rhythm, April, 2017. Oral presentation.

The Role of Predictability in Beat Perception (Hoddinott, J.). Symposium on Timing and Rhythm, April, 2018. Oral presentation.

Awards

9/2018:	NSERC-Create Complex Dynamics Graduate Award.

Relevant Work/Volunteer Experience

9/2016 – 4/2017:	Teaching Assistant, PSYC 1000, University of Western Ontario.
9/2017 – 4/2018:	Teaching Assistant, PSYC 1000, University of Western Ontario.
9/2017 – 4/2018:	Graduate Reviewer, Western Undergraduate Psychology Journal.